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Theoretical Comparison of Signal to Noise Ratios for

Various Carrier Systems

In a memorandum of June 16, 1955 entitled "Investigation of Transmission
Features of Phase Modulation Carrier System of Panhandle Electric
Construction Company", Table I compares the signal to noise ratio of the
above system with those of single and double sideband amplitude modulated
carrier systems. This table indicated that, for the same peak power, the
Panhandle PM system has about an 8 db S/N advantage over a single sideband
AM system.

This table was recently discussed very briefly with Dr. H. Nyquist
(inventor of vestigial sideband carrier transmission). Dr. Nyquist
questioned the above figure of 8 db advantage and suggested a figure of
about one db disadvantage instead.

As a result of this conversation and after further reading of the *source
material for the memorandum of June 16, 1955, the attached Table II was
prepared to replace Table I of the memorandum of June 15.

The top part of Table II compares signal to noise ratios for various
carrier systems and for ratios of 10 db or better. "White", i.e., thermal-
like noise is assumed. The comparison is on the basis of the same peak

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* Modulation Theory by H. S. Black
  Rural Power Line Carrier - Field Comparison of AM, PM and FM by
D. T. Osgood and H. Kahl.

modulated carrier power. The values of relative unmodulated carrier power and of relative sideband power are given. Therefore, comparisons of relative S/N ratios can be readily made for different assumptions as to output power.

Relative S/N ratios in db are given for both 1000 cycle and voice modulation. Voice waves were assumed to have a peak factor of 6 db instead of the 3 db figure for single frequency waves. While the voice wave peak factors are much greater than 6 db, the comparison was made for the maximum phase deviation (1.2 radians) of the PM Panhandle system. This assumes a loud talker at the voice frequency input of all systems. With loud talkers there is usually considerable "peak-chopping" in the carrier terminal apparatus.

Table II shows that the Panhandle PM system has an S/N disadvantage of 1.4 db when compared to a single sideband AM system and when 1000 cycle modulation is assumed. This figure was computed from the theory of H. S. Black and checks Dr. Nyquist's estimate of one db disadvantage very well. For voice modulation, the PM system has a 1.6 db advantage over a single sideband AM system. In computing S/N ratio, the average power (in dbm) in voice frequency AM sidebands was taken as the signal strength. The voice frequency AM signal strength expressed in VU would be about 2 db greater.

As pointed out by Osgood and Kahl, for the same carrier output tube, a PM system can have about 3 db more peak power than an AM system since linear amplification of the modulated signal is less important in the case of the PM system. This 3 db might be taken as an additional S/N advantage for the

PM system. On the other hand, Osgood and Kahl point out that for atmospheric static the advantage of PM over AM is about 3 db less than for "white noise". Since summertime static is apt to be the important source of noise with open wire carrier systems, the two figures of 3 db about offset each other.

Table II also compares the Panhandle PM system with double sideband AM systems. For speech modulation or for 55% 1000 cycle modulation, the PM advantage is 10.6 db. A 1000 cycle modulation of about 50% might be used to calculate S/N ratio for speech.

The lower part of Table II gives the experimental data of Osgood and Kahl on relative signal-to-noise ratios for AM, PM and FM and for white noise. The advantage of PM or FM is large because the maximum phase deviation or maximum frequency deviation is much greater than for the Panhandle PM system. The observed values check well against values calculated according to the method of H. S. Black as discussed below.

The method of calculating the relative S/N ratio for AM systems is simple. The relative noise ratio in db is subtracted algebraically from the relative sideband power. Double sideband systems receive noise power in the audio band from both sidebands. The audio noise power is twice as great or 3 db up from that of single sideband systems.

For the same peak power in DSB and SSB systems, the peak voltage must be the same for the two types of system. For 100% modulation, the peak voltages for DSB unmodulated carrier and for sideband must each be one-half of (6 db down from) the sideband peak voltage of the SSB system. For single frequency modulation, the r.m.s. DSB voltages and the average power

values are also 6 db down. For 100% DSB voice modulation, the unmodulated average carrier power is 6 db down but the average sideband power is 9 db down. This results from the assumption of 6 db peak factor for speech rather than 3 db peak factor as in the case of single frequency.

For 1000 cycle modulation of less than 100%, the sum of the peak unmodulated DSB carrier voltage and the peak sideband voltage is made equal to the peak SSB voltage. For example, call the r.m.s. SSB voltage unity (0 db) and the peak SSB voltage 1.414 (+3 db). For 55% DSB modulation, let C_p = unmodulated carrier peak voltage and S_p = sideband peak voltage. Then S_p = .55 C_p and $S_p + C_p$ = 1.414. It results that C_p = .914 (-.8 db) and S_p is .5 (-6 db). The r.m.s. voltages and average power values in db are 3 db down from the peak voltage values or -3.8 db and -9 db as given on Table II.

The relative S/N ratios for FM and PM systems were obtained from the theory of H. S. Black as follows:

Let D = S/N ratio in db for double sideband system 100% modulated by a single frequency.

F = S/N ratio in db for FM system modulated by a single frequency.

P = S/N ratio in db for PM system modulated by a single frequency.

For the same unmodulated carrier frequency and for same audio band width:

$$F - D = 20 \log_{10} \left[\sqrt{3} \ \frac{\triangle f}{fa} \right] \text{ in db.}$$

$\triangle f$ = maximum frequency deviation in cycles.

fa = audio band width in cycles.

$$P - D = 20 \log_{10} \left[\phi \, m \right] \text{ in db.}$$

ϕ = maximum phase deviation in radians.

The F - D formula was given (in different notation) by H. S. Black. The P - D formula was derived by the writer using the method of Black. Since the P - D formula checked well with the Osgood - Kahl experimental results, it seems reasonable to use it for studying the Panhandle PM system.

The maximum phase deviation of the Panhandle system is 1.2 radians and P - D is + 1.6 db. This is the PM advantage over DSD for the same unmodulated carrier power and single frequency 100% modulation. As shown by Table II, for the same peak power the DSB unmodulated carrier is down 6 db and, therefore, the advantage of PM over 100% modulated DSB is 1.6 + 6 = 7.6 db. In the case of SSB, the noise in the audio band is 3 db less than with PM and the advantage of PM over SSB is + 1.6 - 3 = - 1.4 db or a slight disadvantage.

<div align="right">Arthur G. Chapman</div>

Table II

Theoretical Comparison of Signal to Noise Ratios for
Various Carrier Systems, for "White Noise", for
S/N Ratios of 10 db or more and for same
Peak Modulated Carrier Power

Audio Band Width of 3 Kilocycles

Type of Carrier System	Type of Modulating Signal	Rel.Unmod. Carrier Power	Side Band Power	*Relative Noise Power	Relative S/N	Rel. S/N 0 db
Single Sideband	1000 cycles		0 db	0 db	0 db	
Double S.B.) 100% Mod.)	1000 cycles	-6	-6	+3	- 9	
Double S.B.) 5% Mod.)	1000 cycles	-3.8	-9	+3	-12	
Phase Mod.,Max.) Phase Dev. 1.2 radians	1000 cycles	0	-2.9	+3	- 1.4	
Single Sideband	Speech		-3	0	- 3	
Double S.B.) 100% Mod.)	Speech	-6	-9	+3	-12	- 9
Phase Mod.,Max.) Phase Dev. 1.2 radians)	Speech	0	-2.9	+3	- 1.4	+ 1.6

* This reference is different than that for carrier or sideband power.

Bell System Experimental Comparison

Type of Carrier System	Type of Modulating Signal	Rel.Unmod. Carrier Power	Side Band Power	Relative Noise Power	*Relative S/N Observed	*Relative S/N Calculated
Double S.B.) 100% Mod.)	1000 Cycles	-9 db	-9 db	+3 db	0 db	0 db
Phase Mod.,Max.) Phase Dev. 4.8 radians)	1000 cycles	0 db		+3	+23.5	+22.6
Freq.Mod.,Max.) Freq.Dev. 6000 cycles)	1000 cycles	0 db		+3	+19.5	+19.8

* -12 db S/N for double sideband system taken as reference.

Above comparisons are not for same peak modulated carrier power. Transmitters of all three systems had same output tube. Modulation was increased as much as possible without causing serious speech distortion. Peak power for P.M. and A.M. system was 3 db more than for A.M. system.

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